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High Electric Field Effects in Wide Gap Semiconductors
Semi-Annual Status Report

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During the first six months work has been progressing on five aspects of the proposed research.

1. Samples Preparations - Efforts regarding samples preparation can be divided into two parts:

   (a) Crystal Growth - Two ZnSe growth runs were made, following a technique slightly different from one which we have previously used. The technique utilized a sealed quartz tube with a low argon pressure, low temperature gradient, and a relatively low growth temperature. (cf. M. Toyama and T. Sekiwa, "Kinetics of the Vapor Phase growth of II-VI Compound Crystals. II. Zinc Selenide", Jap. Jour. Appl. Phys., 8, 855 (July 1969.)

   The resulting crystals were generally dark red and grew as clusters of small crystallites. New growth runs are planned which will utilize the original Tufts growth method.

   (b) Electroding - Two types of electrodes and their corresponding techniques have been employed for contacting ZnSe: (1) Alloyed Indium Electrodes (for Ohmic contacts)- prepared by etching samples in a bromine-methanol solution, followed by alloying 99.5% In/0.5% Ga pellets at $\lesssim$ 650°C. in an hydrogen atmosphere. As reported below, according to the point contact probe results, this does lead to Ohmic contacts (provided the alloying temperature is < 650°C and heat is applied for $\lesssim$ 5 seconds; (2) Semi-Transparent Evaportated Gold Electrodes (for barrier contacts)- prepared in a vacuum system by a conventional vacuum evaporation technique: a molybdenum boat was heated in an atmosphere of pressure $\lesssim 10^{-6}$ torr. The thickness of the evaporated gold layer was monitored by a Tufts-built quartz-crystal oscillator thickness monitor. This yielded semi-transparent layers (visible transmission $\simeq$ 40%) for use in the time of flight mobility measurements.

2. Electric Field Mapping- Two types of probes for determining the electric field distribution in the samples have been under development:

   (a) Point Contact Probe - A first-generation shielded tungsten point contact probe assembly is nearly completed. Dc measurements were made on a Tufts-grown ZnSe sample with two alloyed indium electrodes. A bridge circuit with a Keithley 610B electrometer (impedance $\simeq 10^{14}\Omega$) as a null indicator was used. The results indicated that the indium alloying technique employed led to Ohmic contacts since the measured potential distribution was linear. Shown in Figure 1 is a diagram of the circuit utilized for these potential measurements.

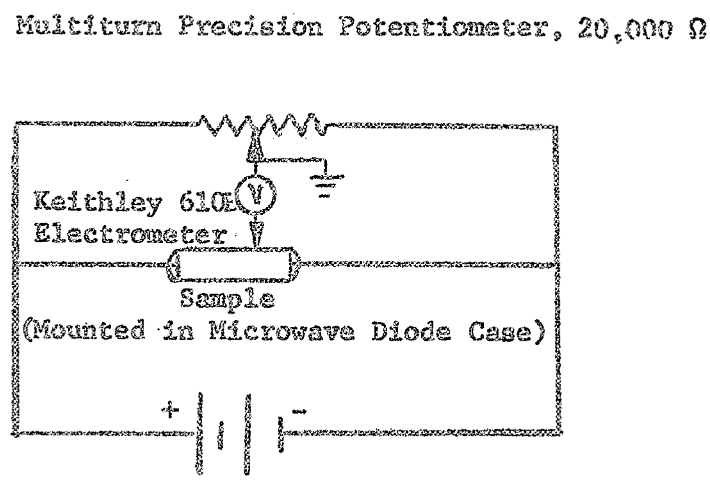

Figure 1: Circuit Diagram for Point Contact Probe Measurement

Optical Electric Field Probe - All the II-VI compounds exhibit a linear electro-optic effect (Pockels effect). It was therefore decided to develop an optical probe that would utilize the Pockels effect for measuring inhomogeneities in the electric field of our samples. In particular, by spatially modulating the sample, together with appropriate detection, it appears that one can determine local charge density variations with a sensitivity determined by the frequency of the spatial modulation. With the Pockel's effect, one can obtain a signal proportional to the local electric field. (Not truly "local", but an average over the optical beam diameter, practically $\gtrsim 1\,\mu$.) If S is the processed signal, ε is the "local" electric field, and x the position of the region in the sample being probed,

$$S\,(x) \sim E\,(x). \qquad (1)$$

If $x = x_o + \Delta x \sin \omega t$,

$$S(t) \sim \left.\frac{\partial E}{\partial x}\right|_{x_o} \Delta x \sin \omega_m t. \qquad (2a)$$

Differentiating, (2a) becomes:

$$S^1 = \frac{dS}{dt} \sim \omega_m \frac{\partial E}{\partial x} \Delta x \cos \omega_m t \qquad (2b)$$

From the one-dimensional Poisson's equation $\frac{dE}{dx} = \rho/\varepsilon$, (2a) and (2b) become, respectively,

$$S \sim \frac{\rho(x_o)}{\varepsilon} \Delta x \sin \omega_m t, \qquad (3a)$$

and $$S^1 \sim \frac{\omega_m}{\varepsilon}\, \rho\,(x_o)\;\; \Delta x\;\; \cos \omega_m t. \qquad (3b)$$

$\rho\,(x_o)$ = charge density clb/m^3) at x_o, and ε = dielectric constant ($\simeq 10\,\varepsilon_o$ for most II-VI compounds).

Equations (3a) and (3b) indicate that the technique should yield a direct measure of the "local" charge density and that the sensitivity of the technique can be in direct proportion to the spatial modulation frequency ω_m.

At present, a conventional setup for measuring the electro-optic coefficient in ZnSe is being explored. This will allow calibration and provide experience. It is planned that a photoexcited masked crystal be used as a reference sample for establishing the feasibility of this charge density measurement technique.

3. Photo-Hall Investigations - Hall samples have been prepared and measured from ZnSe crystals grown: at Tufts, at IBM, and at Bell Telephone Laboratories. Additional samples are presently being prepared from crystals grown at Wright-Patterson. The results obtained at room temperature are summarized in Table 1.

TABLE 1

Results of Photo-Hall Investigations at Room Temperature

Crystal	Subdued Light Conditions $\mu_H \left(\frac{cm^2}{volt\ sec}\right)$	Subdued Light Conditions $n(cm^{-3})$	Intense Microscope Illuminator Condition $\mu_H \left(\frac{cm^2}{volt\ sec}\right)$	Intense Microscope Illuminator Condition $n(cm^{-3})$
IBM - ZnSe (IBM-1)	20 ± 10	$\sim 10^{13}$	40 ± 10	$\sim 10^{14}$
Bell Telephone-ZnSe (BLV-2)	(Difficult to Measure)		20 ± 10	$\sim 10^{12}$
Tufts-ZnSe (JLH-1)	(Difficult to Measure)		200 ± 40	$\sim 10^{11}$

(All samples were n-type at room temperature)

Shown in Figure 2 is a sketch of the circuit used for the photo-Hall measurements. A redesign of the illumination system is presently being worked upon, and new Hall samples of Wright Patterson CdS and ZnSe are being prepared for measurements.

4. Characterization of Traps - Two techniques (in addition to the photo-Hall method) are being explored for characterizing the traps in our samples.

(a) Capacitance - Bias Voltage Method - Apparatus and samples are being prepared to take advantage of the trap-caused deviation from a linear $1/C^2$ versus bias voltage curve predicted for a Schotlky barrier. (A. Goodman, "Metal-Semiconductor Barrier Height Measurement by the Differential Capacitance Method-One Carrier System", Jour. Appl. Phys., 34, 329 (1963)). Preliminary measurements on IBM ZnSe samples indicate that for low bulk resistance, large barrier capacitance samples, this technique can detect traps with good sensitivity.

(b) Thermally Stimulated Current Method - Apparatus has been rebuilt and is undergoing evaluation for utilizing the thermally stimulated current method for char-

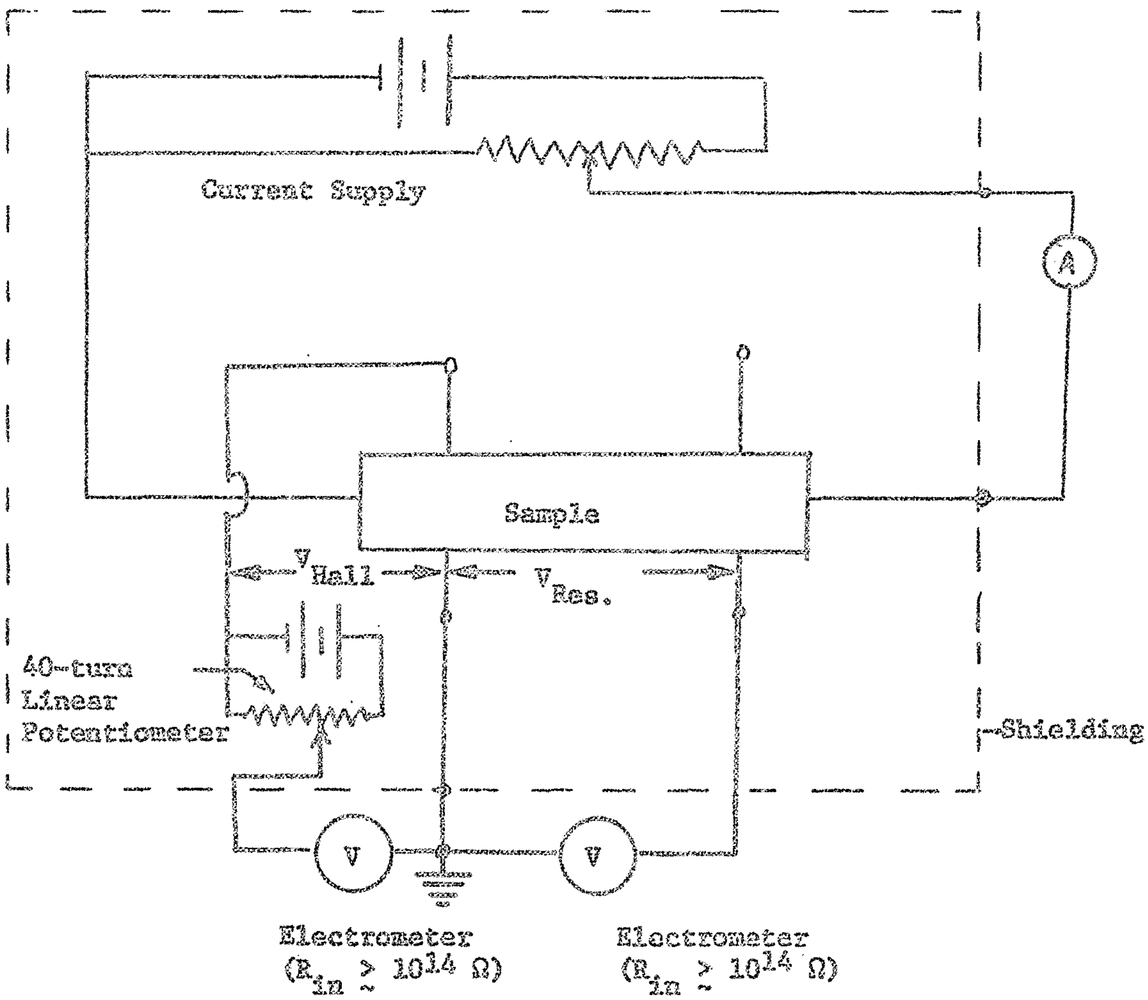

Figure 2: Circuit Used for the Photo-Hall Measurements.

acterizing traps. The apparatus should be capable of operation in the temperature range 100°K - 400°K.

5. <u>Time of Flight Mobility vs. Electric Field Measurements</u>

A considerable effort has been devoted to developing a system to measure the mobility-electric field characteristics of the wide band gap semiconductors, utilizing a short (half width < 20 nanoseconds) light flash.

The shielding and gain of the detector circuit allow the detection of currents as small as 250 nanoamperes and as short as 20 nanoseconds. (The time resolution is limited by the use of a 50 mHz. oscilloscope, which, in turn, is required because of the amplitude jitter associated with the light flash; otherwise an available Tektronix 564 sampling oscilloscope could be used.)

The measurement technique is based upon the principle that a short enough light flash (short compared to such times as transit, dielectric relaxation, carrier life, and diffusion-times) would photoexcite a spatially narrow "sheet" of hole-electron pairs. The "sheet" would rapidly separate. The holes would be removed at a negatively biased semi-transparent electrode. The electrons (or holes) in turn would drift in the direction of the other electrode, biased positively. For a uniform electric field, the drifting electrons will cause a steady current to flow until the electron "sheet" arrives at the positive electrode. At that time there should be an abrupt cessation of current flow. (The roles of the holes and electrons reverse when the positively biased electrode is photoexcited.)

A number of ZnSe samples from Tufts-grown crystals, and a few samples from a Wright-Patterson crystal have been measured with this technique. Shown in Figure 3 is a sketch of the response of a typical Tufts-grown sample. Similar results have been obtained with the Wright-Patterson samples, although the decay time is longer.

The current decay during transit might be caused by: (a) short lifetimes; (b) nonuniform electric field; (c) space-charge relaxation; (d) trapping effects; and/or (e) detection circuit response. These possibilities are all being checked out and, additionally, samples of CdS are also being prepared for this experiment.

Synposis - Progress is being made in five areas towards better understanding of previously observed anomalous high electric field effects in wide gap semi-conductors. This includes: (1) samples preparations; (2) electric field mapping; (3) photo-Hall investigations; (4) traps characterizations; and (5) time-of-flight mobility measurements. A major emphasis will continue to be to obtain a time of flight mobility-electric field relationship and to correlate the results with other studies. The preparation of additional samples and improved apparatus are the steps that will be taken to obtain more information from this experiment.

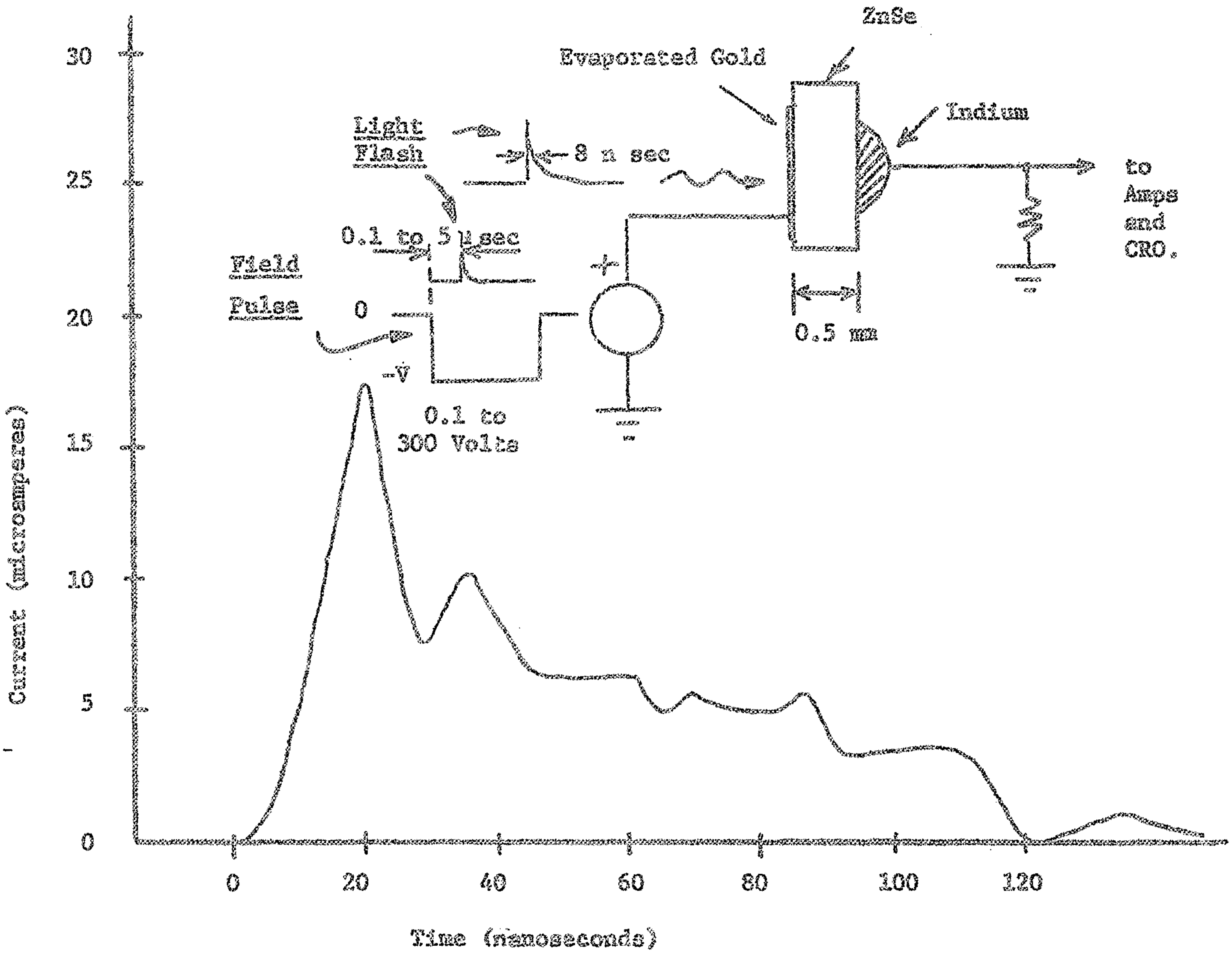

Figure 3: Light flash response of sample 1-a with 75 volt field pulse applied at $t = 0$.